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Numerical Analysis of Flowing for both Adiabatic Water-air Flow Patterns and Their Transitions in a Horizontal Tube

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Abstract

Both the loss of flowing resistance and dynamic performance of fluid transportation for water-air two phases in a horizontal tube is closely related to its flow pattern, which is different from fluid flow of single phase. At the present work, according to Baker's adiabatic flow pattern map of water-air, a VOF gas-liquid interfacial tracking model was adopted to numerically analyze characteristics of adiabatic water-air flow pattern and their transitions. Parameters, including volume fraction, velocity and pressure contours, were obtained for stratified, plug and annular flows. Results show that distributions of both pressure and velocity change with flow patterns. Pressure has a stratified distribution at the cross-section of tube for stratified flow, and pressure of air is lower than that of water. For transition from plug to annular flows, local static pressure intensively rises. This demonstrates that it is possible to cause liquid obstruction. For transition from annular to stratified flows, drop of static pressure obviously increases.

Keywords: Two phases flow, flow pattern, transition, water-air, flowing;

1. Introduction

Fluid flow of gas-liquid two phases in a horizontal tube has widely applied to different fields, including power, chemical industry and petroleum engineering. Because of different working conditions and thermophysical properties, fluid flow of gas-liquid two phases in a horizontal tube displays different flow patterns, which affects security and economy of mechanical equipments. Annular flow is safety and economy, both plug and slug easily blocks liquid, and wavy flow is unstable because variable force and velocity exerted on the interface. Therefore, researches on both flow patterns and theirs transitions are

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valuable to practical engineering application, which is an important key to be considered by the engineering designers.

Flow patterns are complexity because distribution of gas-liquid phase varies with easy deforming interface. It is affected by many factors, including size, shape, tilt angle of the tube, heating conditions, gravity field, surface tension, shear stress between gas and liquid phases. Baker [1] described transition of flow pattern with mass flow of gas-liquid phase. At velocity of gas phase larger than 10m/s, annular flow appears in a horizontal tube; at velocity of gas phase from 0.3m/s to 2m/s, intermittent flow appears; at velocity of gas-liquid phase less than 0.2m/s, stratified flow appears. Mandhane et al [2] analyzed effects of gas-liquid phase reduced velocity on transition of flow pattern. Transition from stratified to slug flow occurs at reduced velocity of 0.15m/s, transition from slug to bubble flows occurs at 4.5m/s. Taitel and Dukler[3] obtained determining condition of flow pattern under some factors, including reduced velocity, tube diameter, pressure, tilt angle and physical properties. Weisman et al [4] experimentally investigated effects of both fluid properties and tube diameter on flow pattern.

In summary, gas-liquid phase flow pattern is caused by many factors, including geometry conditions, parameters of both flowing and physical properties. So, a three dimensional numerical simulation can predict more factors to affect flow patterns and their transitions. Considering the existence of gas-liquid interface, a prediction model is required to capture a gas-liquid interface. Hirt and Nichols [5] firstly proposed VOF model to track the interface. It involved mass, momentum and energy conversion equations. It also defined volume fraction as ratio of liquid or gas volume to total volume in any cell. If a is 0 or 1, the cell is full of gas or liquid, or the cell involves an interface. Gas-liquid interface is determined by an interface construction method. At the present work, the VOF model is used to simulate stratified, plug, annular flows and their transition. Based on results, features of parameters were analyzed.

2 The VOF Model

It is assumed that fluid is incompressible Newton fluid, viscous dissipation is neglected, and Flowing is in three-dimension. A VOF model can be described as follows:

$$\begin{cases} \nabla\cdot(\rho\mathbf{V})=0 \\ \nabla\cdot(\rho\mathbf{V}\mathbf{V})=-\nabla p+\nabla(\mu_{eff}\mathbf{V})+\rho\mathbf{g}+F \\ \nabla\cdot(\rho\mathbf{V}k)=\nabla(\mu_{eff}k)+G-\rho\varepsilon \\ \nabla\cdot(\rho\mathbf{V}\varepsilon)=\nabla(\mu_{eff}\varepsilon)+\dfrac{\varepsilon}{k}(GC_{1\varepsilon}-C_{2\varepsilon}\rho\varepsilon) \\ \nabla\cdot(\alpha_1\rho_1\mathbf{V})=0 \\ \alpha_1+\alpha_2=1 \end{cases} \tag{1}$$

Computations were implemented with a Fluent software. Boundary conditions, including velocity inlet, outflow outlet and non-slip wall, were adopted. A boundary layer grid was used. Linear equation groups obtained by the governing equations discretized with the second order upwind form are couple solved with the methods of Gauss-Seidel and AMG. Pressure is treated with a PISO algorithm (Pressure Implicit with Splitting of Operator) and accurately solved with the pressure-velocity coupling. Relaxing factors are settled as 0.7 for momentum equation, 0.3 for pressure, 0.3 for volume fraction equation, and 0.1 for other equations.

3. Results and Discussion

Figures should be placed at the top or bottom of a page wherever possible, as close as possible to the first reference to them in the paper. Flow pattern and their transitions of adiabatic gas-liquid two phases for air and water were modeled with the VOF model. Parameter's distributions about plug flow ($u_{in} = 2m/s$), annular flow ($u_{in} = 20\ m/s$) and stratified flow ($u_{in} = 0.1m/s$) were obtained, and features of transition from annular to stratified flows and from plug to annular flow were analyzed.

3.1. Parameter's distribution of different flow patterns

Fig 1 shows that parameter's distribution of plug flow ($u_{in} = 2m/s$) in a horizontal tube, including air volume fraction, pressure and velocity. As water with air plug flows into the horizontal tube, its kinetic energy reduces due to friction loss with inner wall, so velocity varies along the tube length, causing deformation of air plug, as shown in Fig 1. Because the front air plug is pushed by the behind one, its tail deforms at the joint point between two air plugs. Air density is less than water density, so air velocity is larger than water velocity. In Fig 1, Static pressure drops along flowing of water with air plug because of friction loss between interior wall and water with air plug. However, Static pressure drops of gas-liquid phase are different, not reaching full developing state. In Fig 1, total pressure dramatically changes between adjacent air plugs, and spreads all directions from the center of adjacent air plugs.

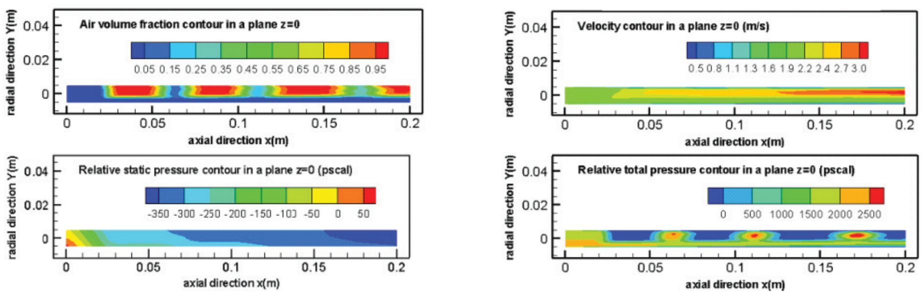

Fig.1. Parameter distribution of plug flow in a horizontal tube

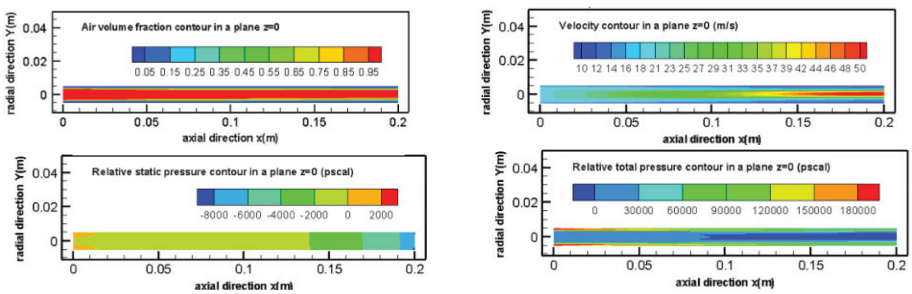

Fig. 2. Parameter's distribution of annular flow in a horizontal tube

Fig 2 shows that parameter's distribution of annular flow in a horizontal tube, including volume fraction, velocity, static and total pressures. The interior wall of the horizontal tube is covered with water, air lies in the center of the horizontal tube, so velocity of air in the center is higher, as shown in Fig 2. Air with higher velocity imposed higher stress shear on water, so water can overcome its gravity to maintain annular flow, as shown in Fig 2. Static and total pressures decrease along the tube length, as shown in Fig 2. Distributions of both velocity and pressure for annular flow are similar to that for single phase flowing and belongs to full development state. So, annular flow is a safe and economic flow pattern.

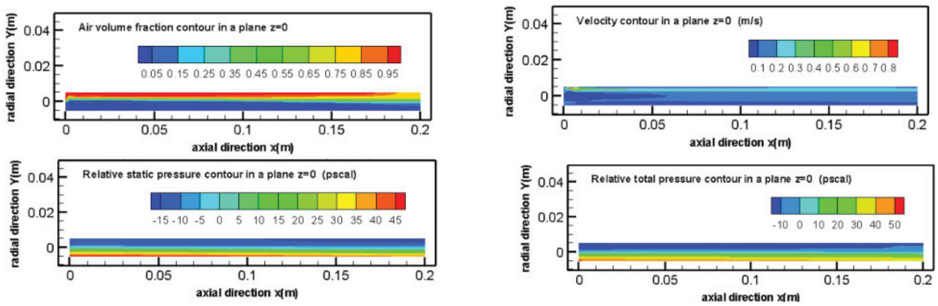

Fig.3. Parameter's distribution of stratified flow in a horizontal tube

3.2. Analysis of transition between flow patterns

Fig 4 shows parameter's distribution of transition from annular to stratified flows. It forms by transforming inlet velocity into $u_{in} = 3\,m/s$ based on annular flow at velocity of $u_{in} = 20\,m/s$. In Fig 4, as inlet velocity reduces, air shear stress reduces and can't overcome gravity of water to maintain annular flow, so water slips into the bottom of the tube along the circumference, gathering there. In the region of transition from annular to stratified flows, velocity of air dramatically rises, and a stratified flow occurs in the rear part of the horizontal tube, as shown in Fig4. Distributions of both static and total pressures meet features of stratified flow, as shown in Fig 4.

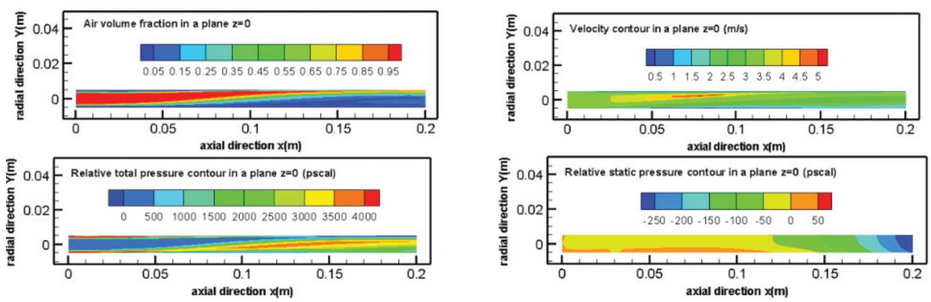

Fig. 4. Parameter's distribution of transition from annular to stratified flow

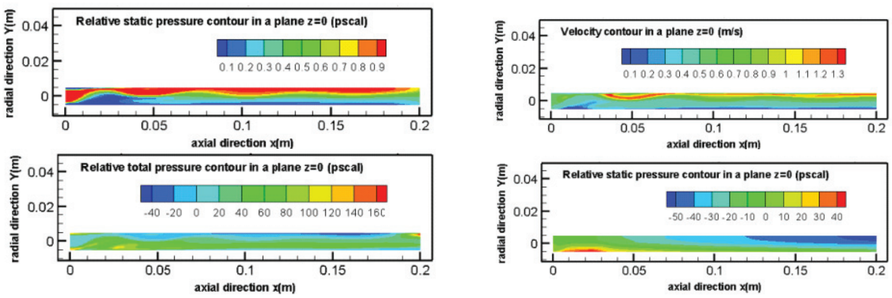

Fig. 5. Parameter's distribution of transition from annular to wavy flow

Fig 5 shows that parameter's distribution of transition from annular to wavy flows. It forms by transforming inlet velocity into $u_{in} = 0.5 m/s$ based on annular flow at velocity of $u_{in} = 20 m/s$. Because of lower inlet velocity, air shear stress decreases, and gravity of water dominates. A large amount of water flows into the bottom from the top of the tube, disturbing both pressure and velocity on the gas-liquid interface. So, wavy flow appears. Static pressure of fluid decreases along the flowing direction, and total pressure also fluctuates. Meanwhile, total pressure of air is lower, and that of water is higher.

Fig 6 shows parameter's distribution of transition from plug to annular flow. It forms by transforming inlet velocity into $u_{in} = 15 m/s$ based on fluid flowing at velocity of $u_{in} = 2 m/s$. Pushed by higher inlet velocity, plug flow leaves out of the horizontal tube and is substituted for annular flow. Static pressure gradually drops along the flowing direction, however, at the joint point where annular flow touches plug flow, static and total pressures ascends and is larger than constant pressure.

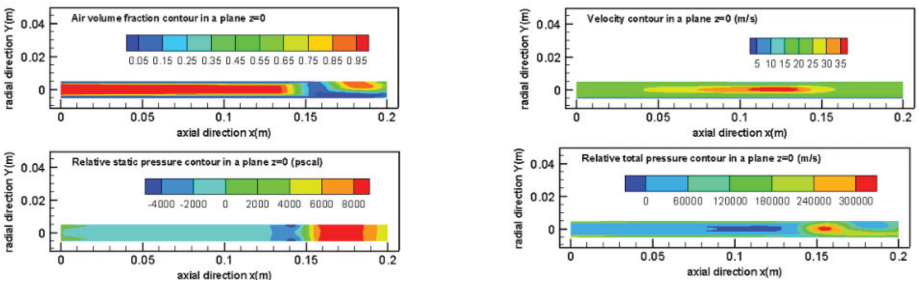

Fig .6. Parameter's distribution of transition from plug to annular flows

4. Conclusion

Using a VOF model, both adiabatic water-air flow patterns and their transitions was numerically analyzed based on a Baker flow pattern regime and parameters' distributions were obtained, including air volume fraction, velocity and pressure. Results show that distributions both pressure and velocity changes with flow patterns. For plug, stratified and annular flows, static pressure of air is lower than that of water, and has obvious stratified distribution at the cross-section of the horizontal tube. During transition from annular to stratified flows, static pressure obviously increases. During transition from plug to annular flow, local pressure obviously goes up, it is possible to occur obstruction liquid.

References

[1] Baker O. Design of Pipelines for Simulations Flow of Oil and Gas, *Oil and Gas Journal*; 1954; 26(7): 185-195

[2] Mandhane J M, Gregory G A and Aziz K A . A Flow Pattern Map for Gas-Liquid Flow in Horizontal Pipeline, Int. J. Multiphase Flow; 1954; 537-554

[3] Taitel Y and Dukler A N E. A Model for Predicting Flow Regime Transitions in Horizontal and Near Horizontal Gas-Liquid Flow, *AIChE Journal*; 1976; 22(1):47-55

[4] Weisman J, Duncan D, Gibson J and Crawford T J . Effects of Fluid Properties and Pipe Diameter on Two-Phase Flow Patterns in Horizontal Lines, *Int. J. Multiphase Flow*;1979;5:437-462

[5] Hirt C W, Nichols B D. Volume of fluid method for the dynamics of free boundary. *J Comput Phys,* 1981;93;273-285